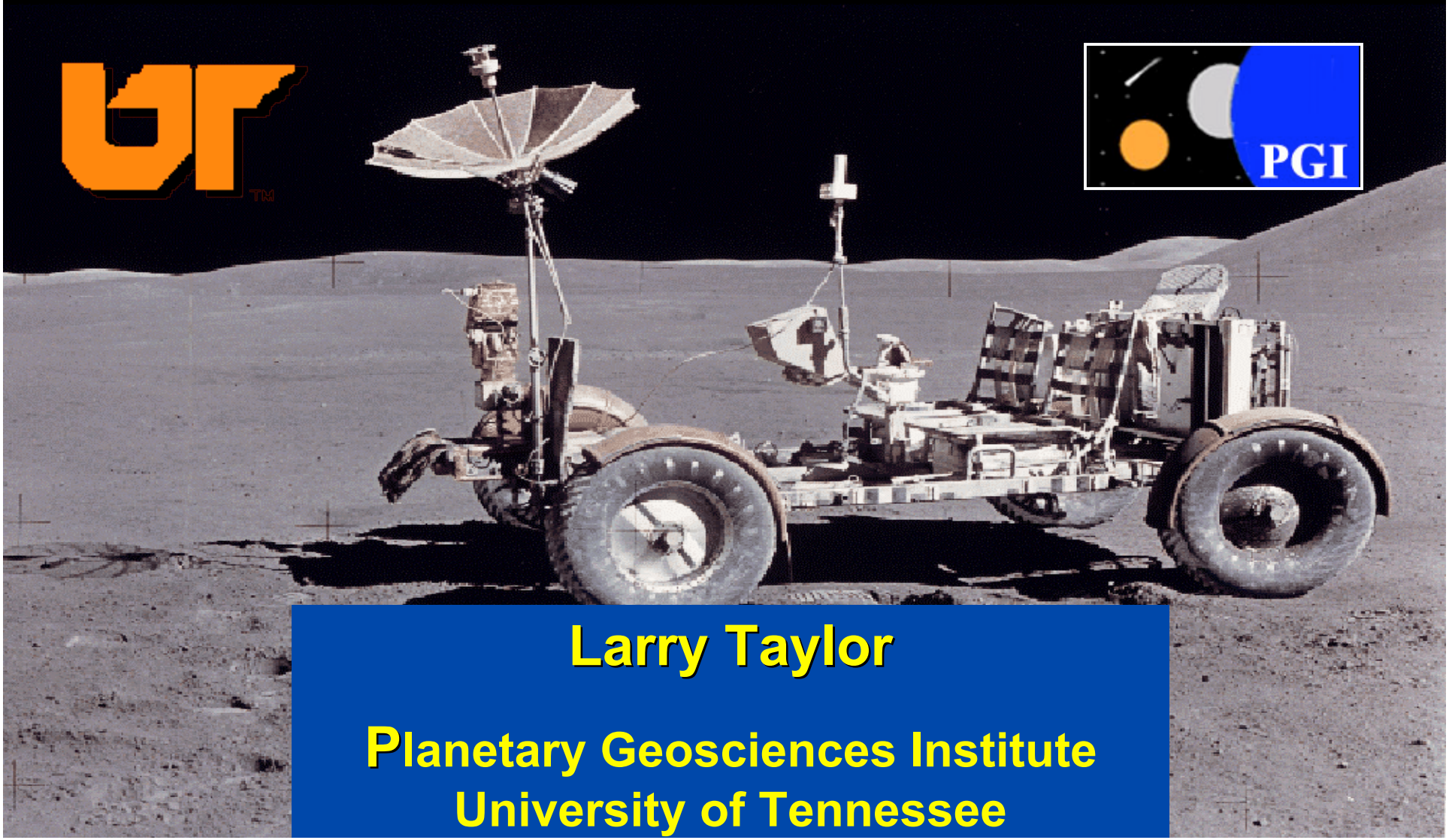
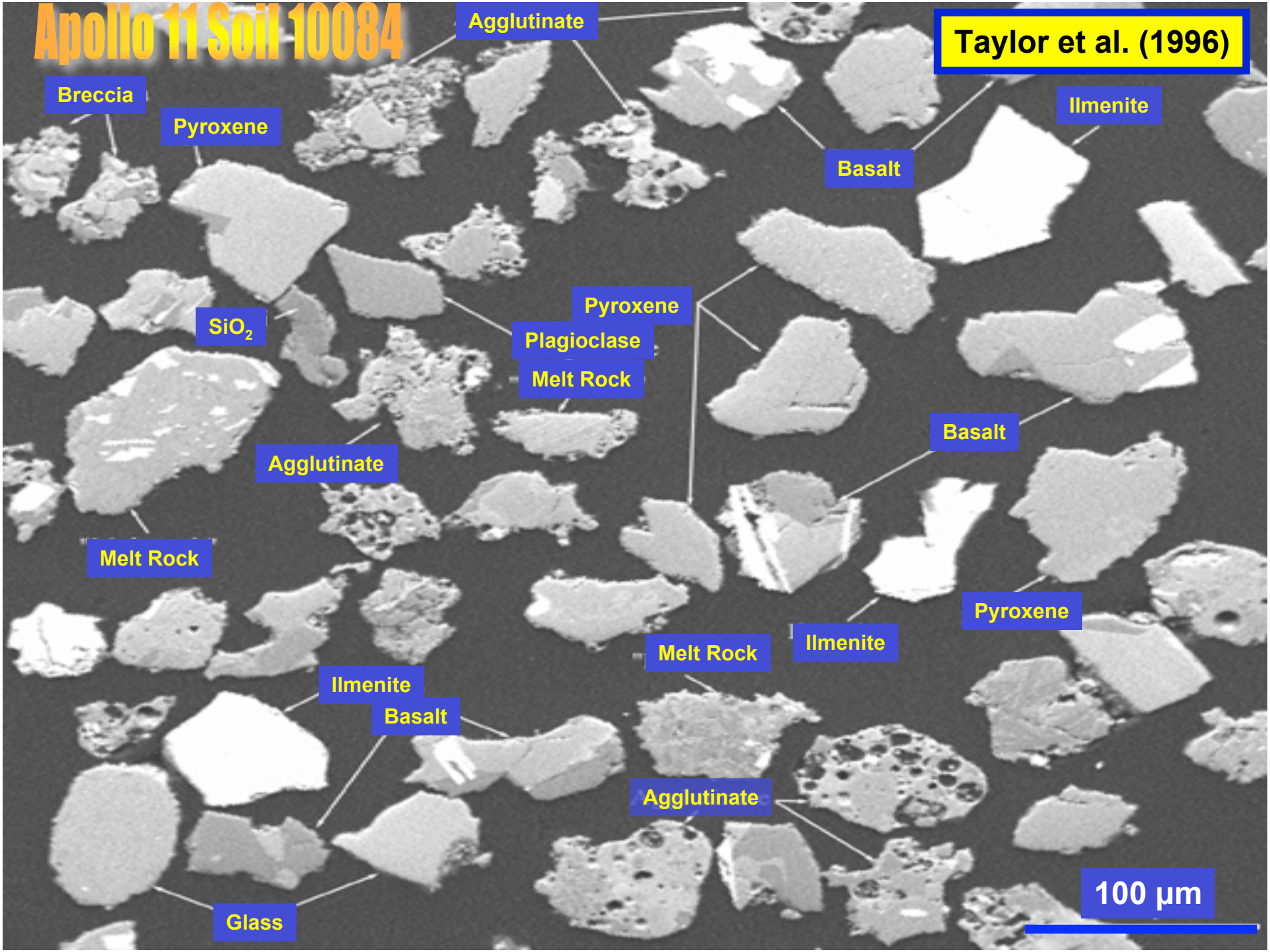
Everything You Ever Wanted to Know about Lunar Dust



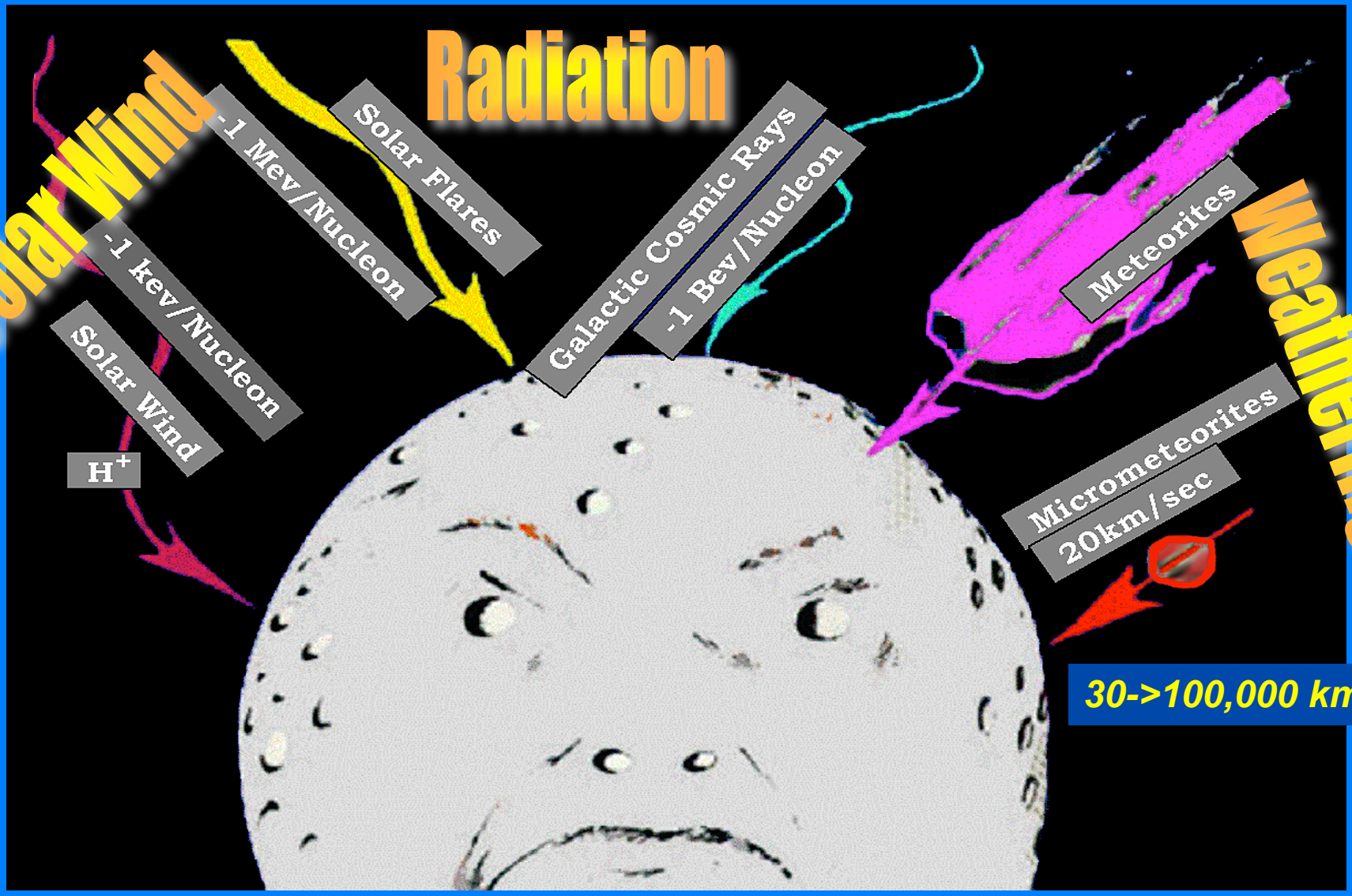
Larry Taylor

Planetary Geosciences Institute
University of Tennessee


Apollo 11 Soil 10084
Taylor et al. (1996)
Agglutinate
Breccia
Pyroxene
Ilmenite
Basalt
Pyroxene
SiO_2
Plagioclase
Melt Rock
Basalt
Agglutinate
Melt Rock
Pyroxene
Ilmenite
Melt Rock
Ilmenite
Basalt
Agglutinate
Glass
100 µm

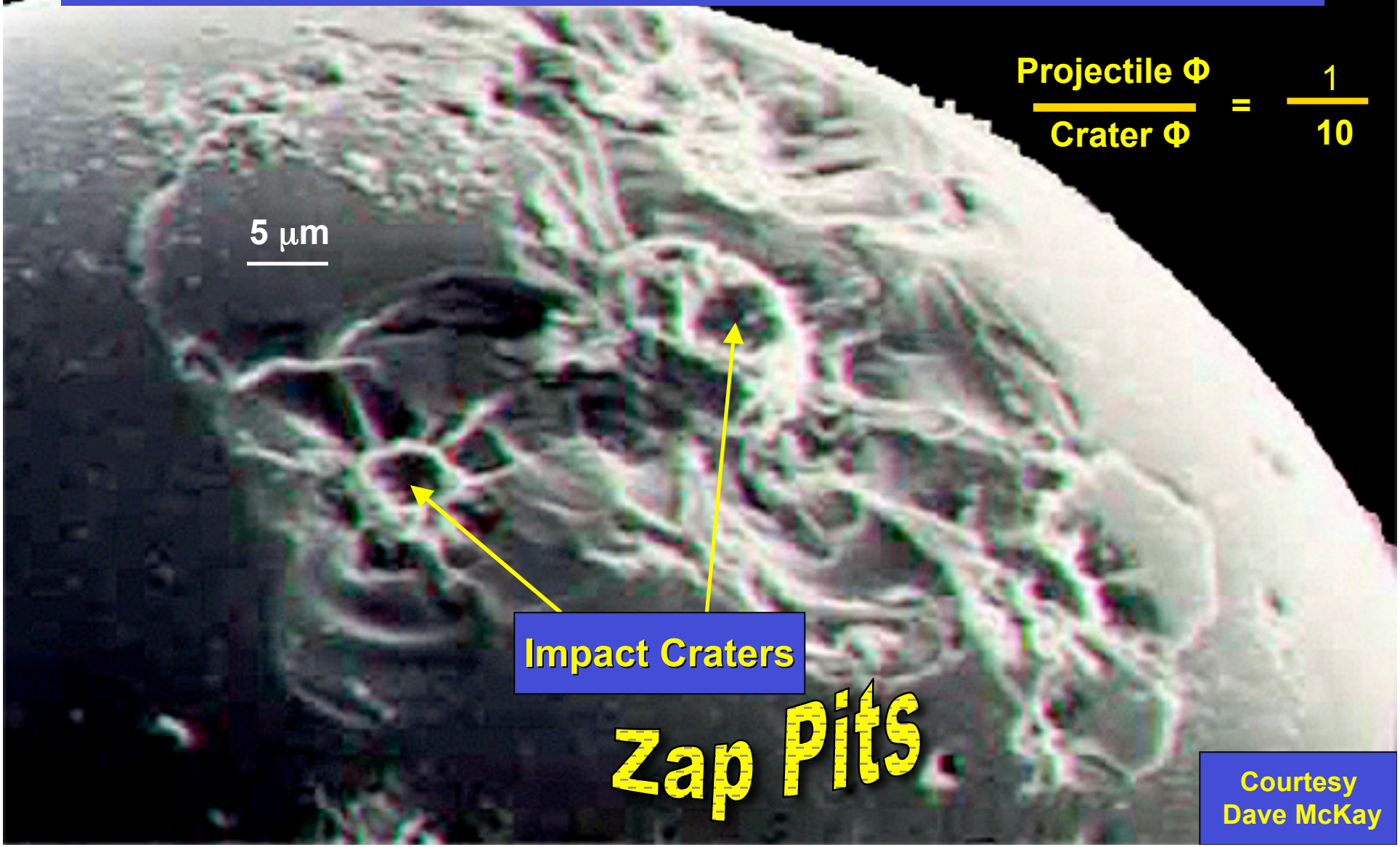
University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Our Unhappy Moon



30->100,000 km/hr

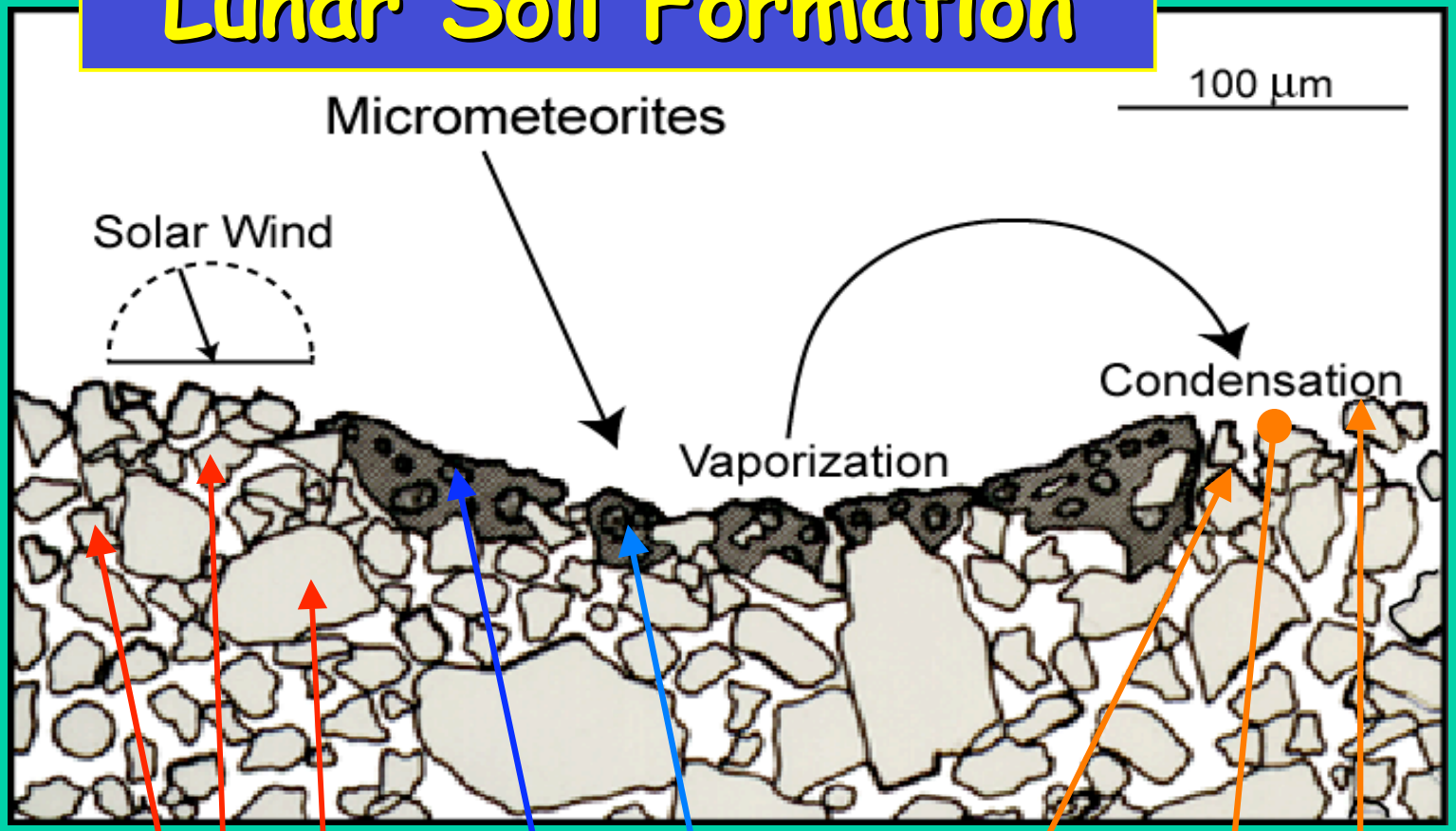
Micrometeorite Impacts on a Lunar Glass Bead



$$\frac{\text{Projectile } \Phi}{\text{Crater } \Phi} = \frac{1}{10}$$

Courtesy
Dave McKay

Lunar Soil Formation

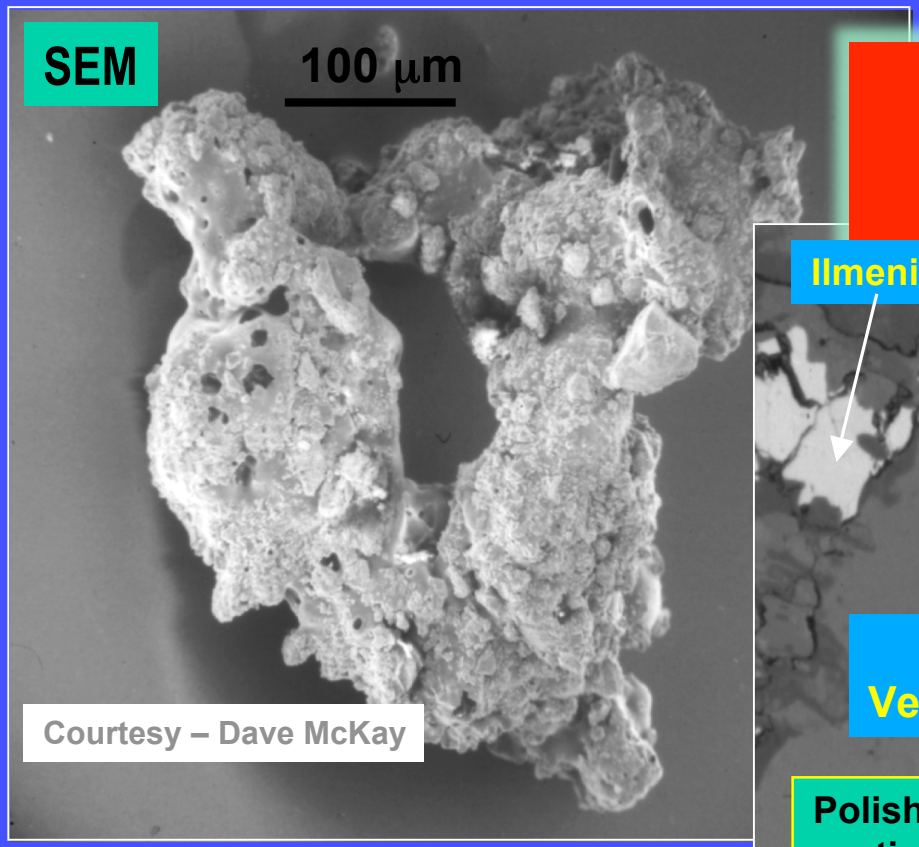


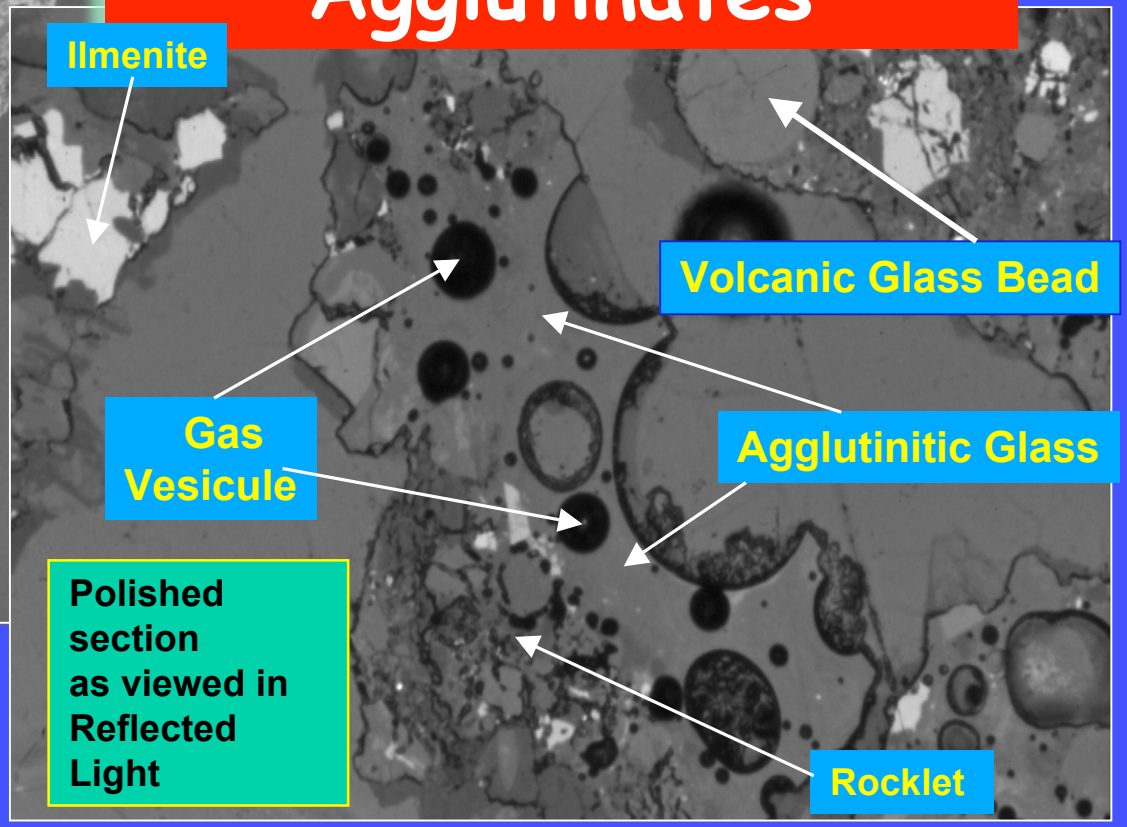
Comminution, Agglutination, & Vapor Deposition

The major Weathering and Erosional agent on the Moon is
Meteorite / Micrometeorite Impacts

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Mare-Soil Agglutinates

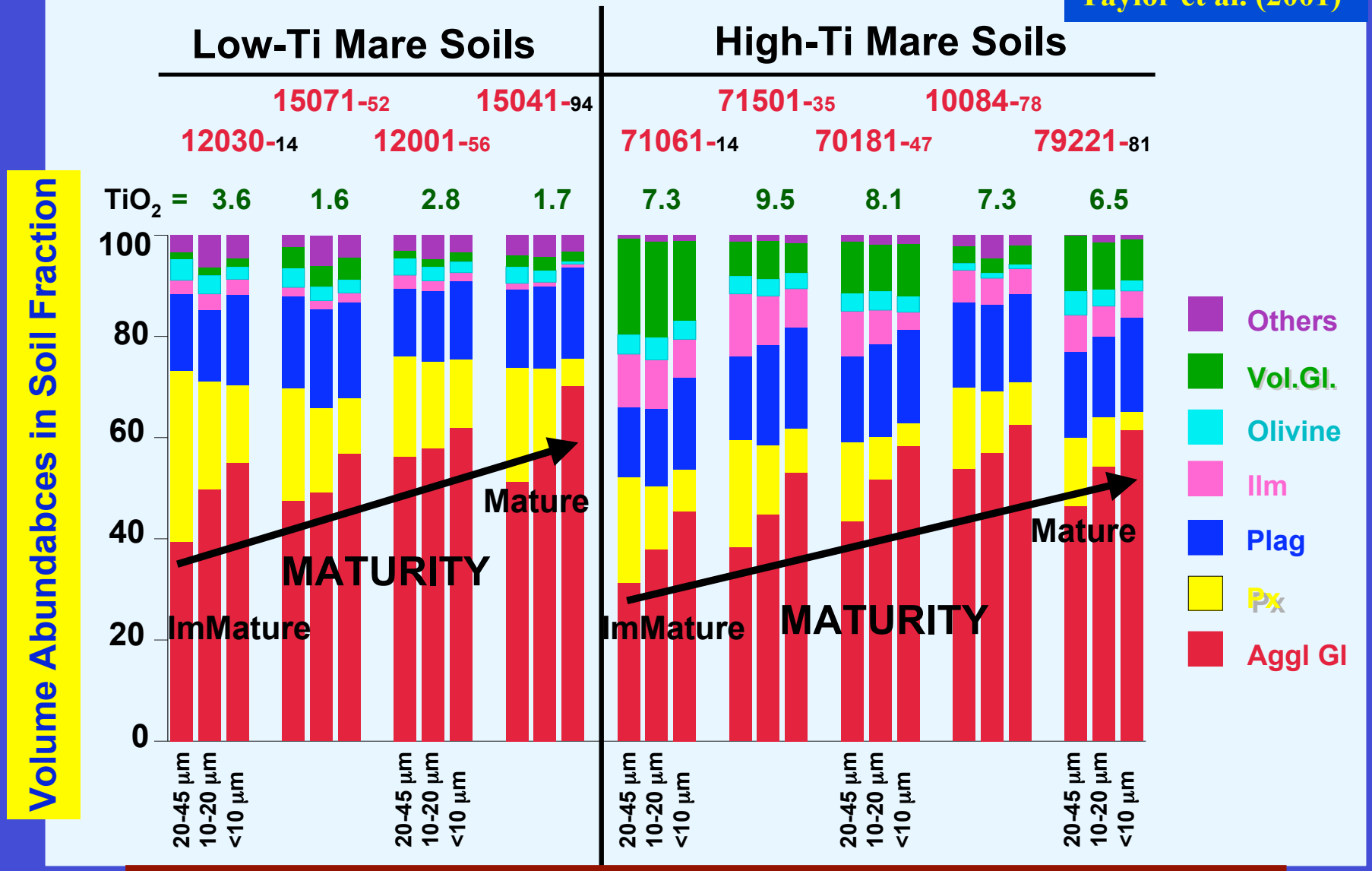




Pieces of minerals, rocklets, and glass welded together by shock-melt glass

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Taylor et al. (2001)

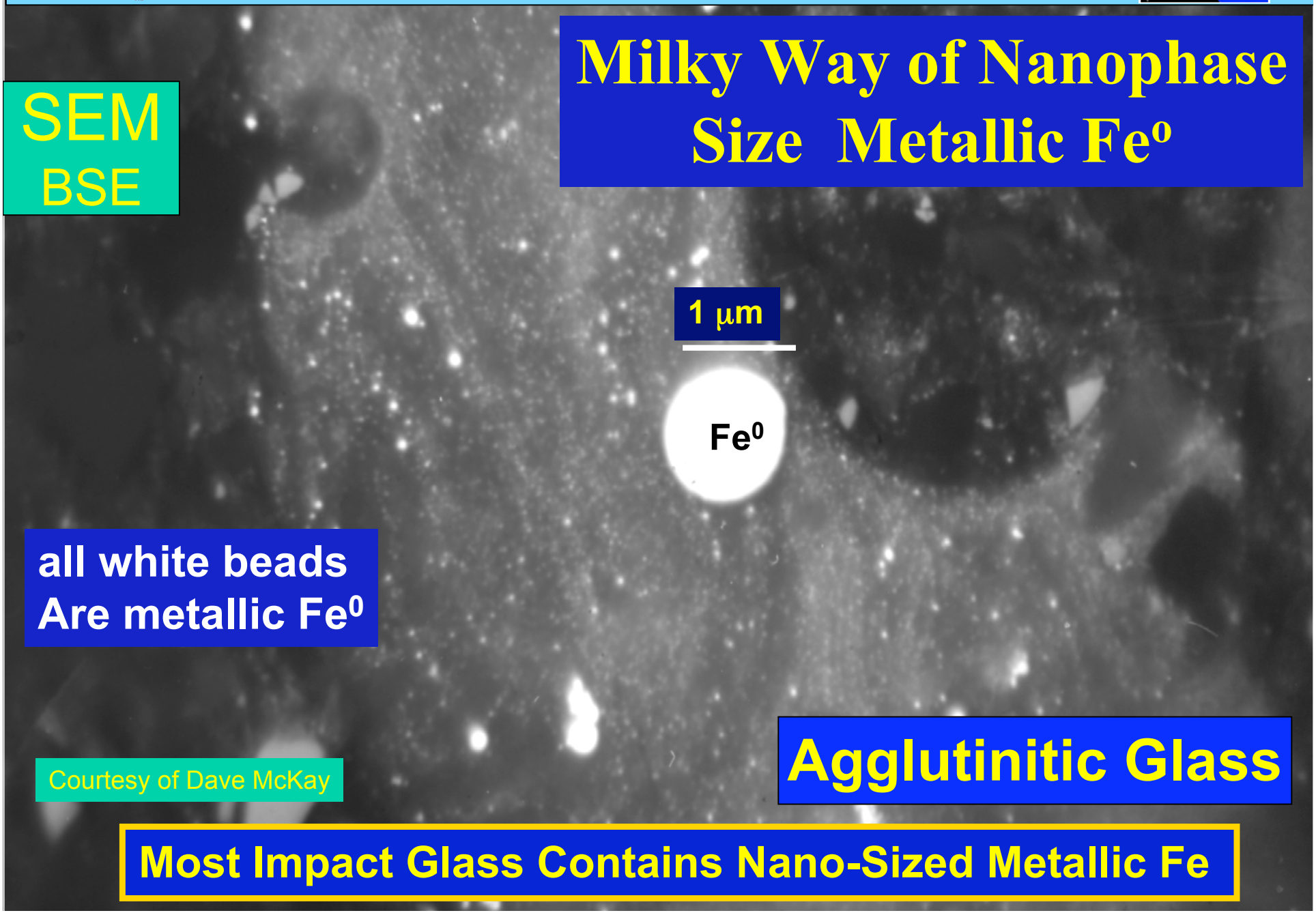


Glass abundances Increase as Grain-Size Decreases

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Milky Way of Nanophase Size Metallic Fe^0

SEM
BSE



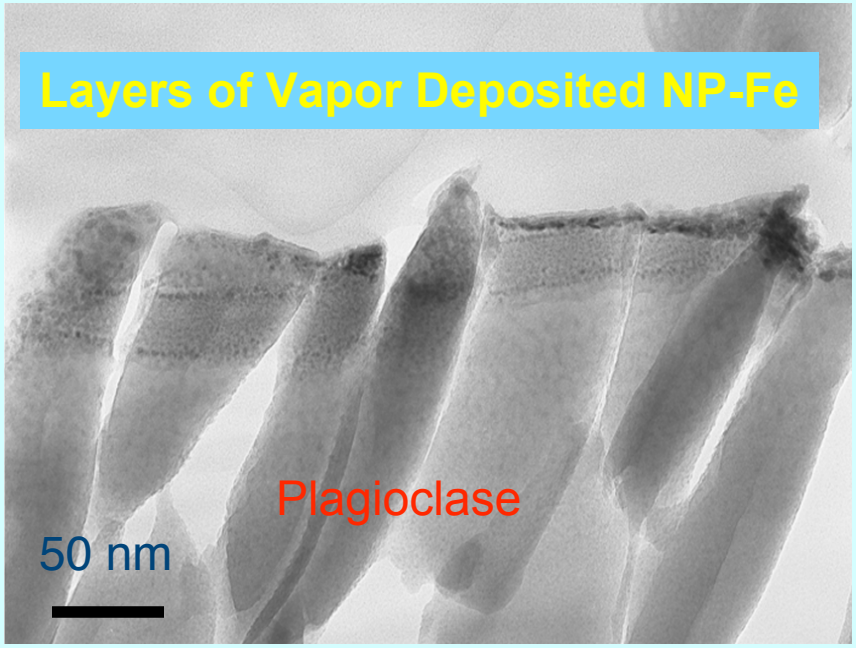
all white beads
Are metallic Fe^0

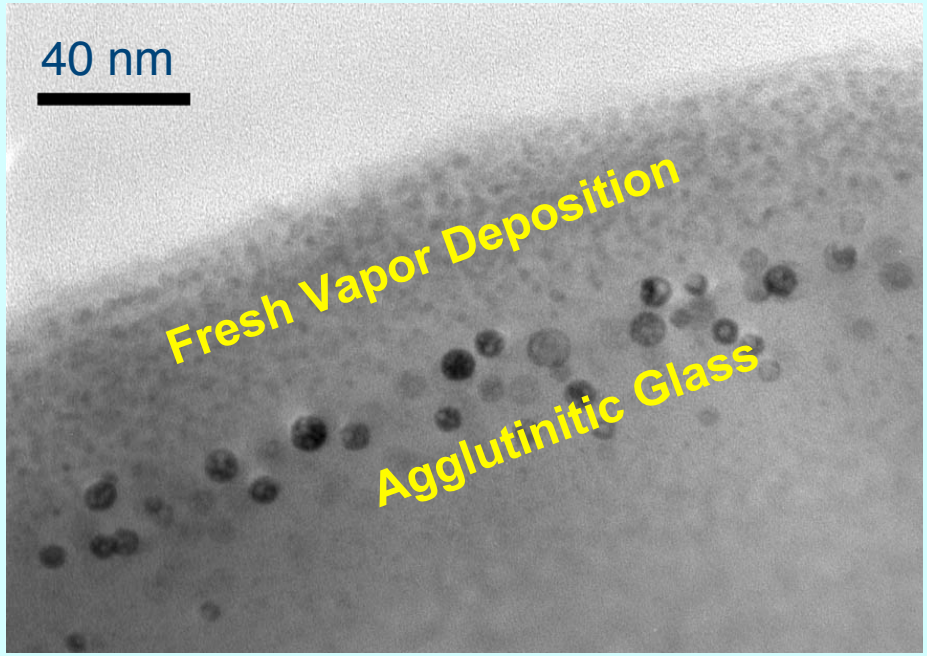
Courtesy of Dave McKay

Agglutinitic Glass

Most Impact Glass Contains Nano-Sized Metallic Fe

Close-Up of Lunar Soil Particles

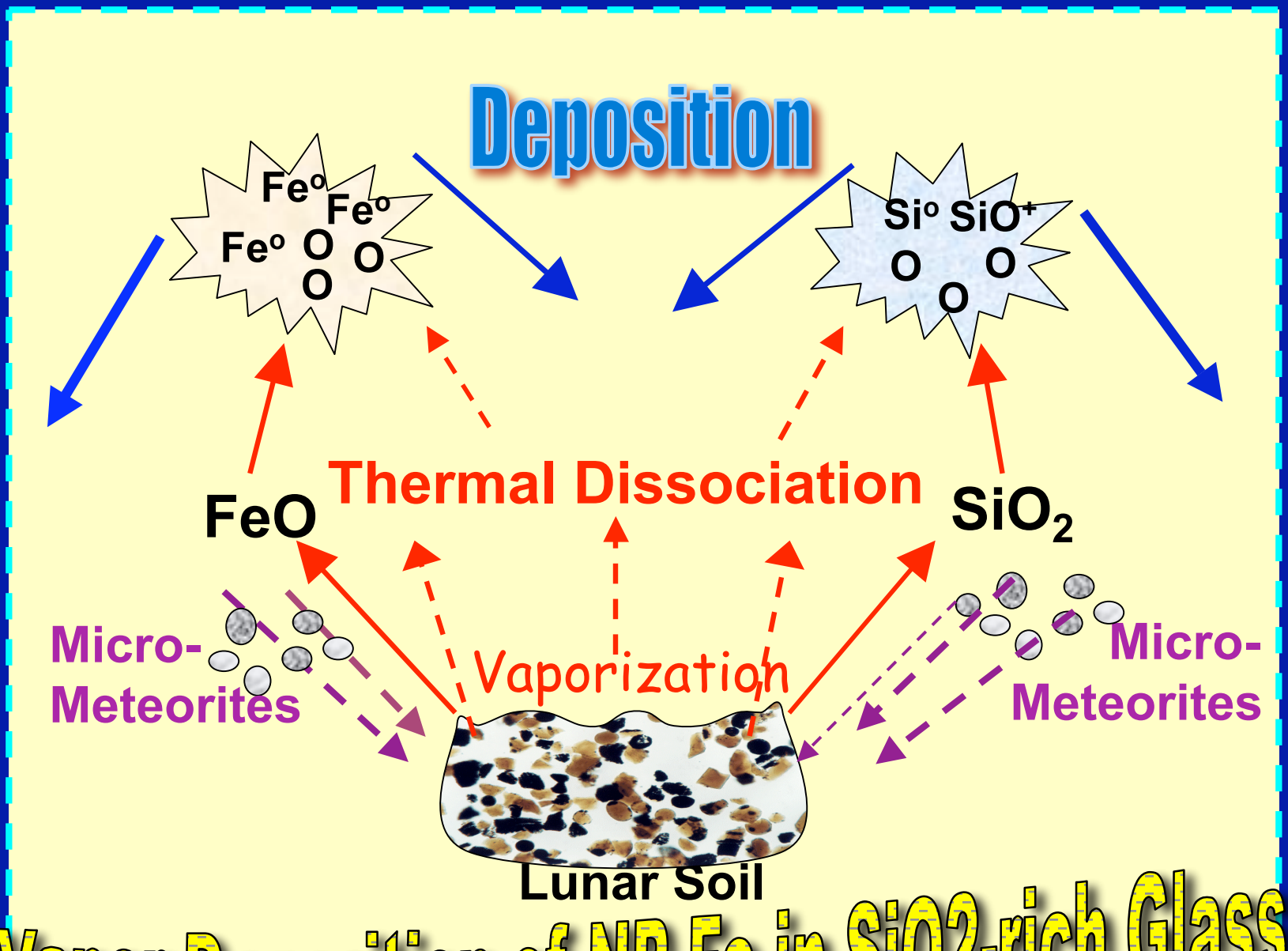




Vapor/Sputter Deposited Rims - TEM

Courtesy of Sarah Noble

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu



Vapor-Deposition of NP-Fe in SiO2-rich Glass

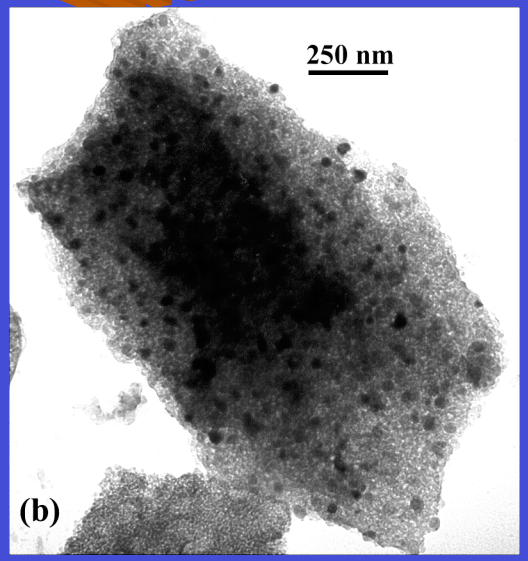
University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

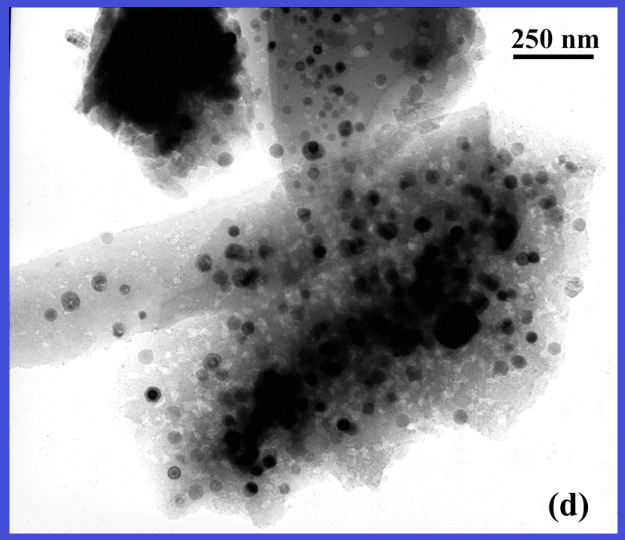
Synthesis of Lunar Glass Simulant with NanoPhase Metallic Fe

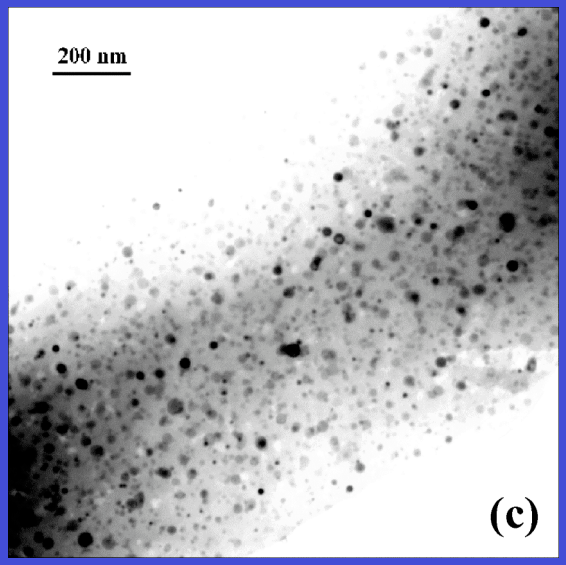
Milky Way of np-Fe^0

all white beads = Fe^0

TEM Photos







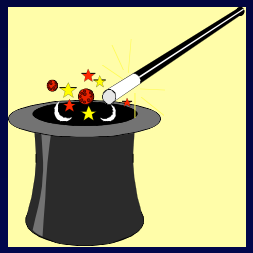
All Black Dots are Nanophase Fe

Concentrations of Solar-Wind Volatile Species in Lunar Regolith Samples, in ppm

	H	He	C	N	Ne	Ar
Apollo 11	20-100	20-84	96-216	45-110	2-11	1.3-12
Apollo 12	2-106	14-68	23-170	46-140	1.2-6	0.5-4.6
Apollo 14	67-105	5-16	42-225	25-130	0.14-1.6	0.4-2.2
Apollo 15	13-125	5-19	21-186	33-135	0.6-108	0.5-2.7
Apollo 16	4-146	3-36	31-280	4-209	0.4-1.2	0.6-3
Apollo 17	1-206	13-41	4-200	7-94	1.2-2.7	0.6-2.6

Haskin & Warren, 1991

80 wt% of Solar-Wind Particles are in the <50 µm Size Split



POLAR SOIL CHARACTERISTICS & SOLAR-WIND

REGOLITH IN PERMANENTLY SHADOWED TERRAIN – PST

40 K imparts brittleness/crushability to soil grains

- ☻ Result could be much finer average grain size for soil
- ☻ SW abundances are surface property; greatly increased surface areas should increase SW.

SW retentivity: a function of maximum diurnal T

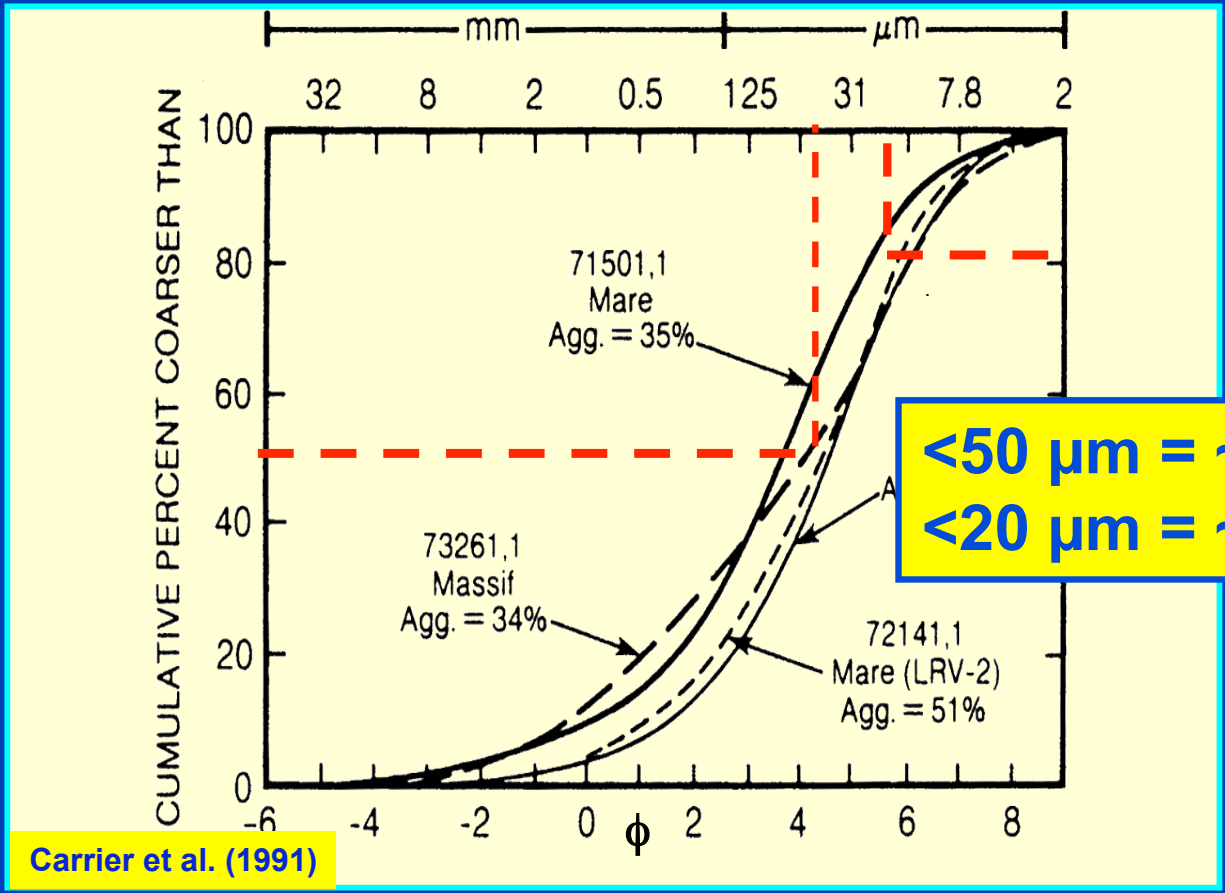
- ☻ Therefore, retentivity of PST soil should be much greater: +125 ^{0}C versus -230 ^{0}C

BOTH TEMP AND FINE-GRAIN SIZE OF SOIL =

GREATLY ENHANCED SOLAR-WIND VOLATILES

2000 ppm Hydrogen, SW or Water, is a "WIN–WIN" Situation

Mare Soil Particle Size Distribution



Carrier et al. (1991)

<50 μm = ~50 wt%
<20 μm = ~20 wt%

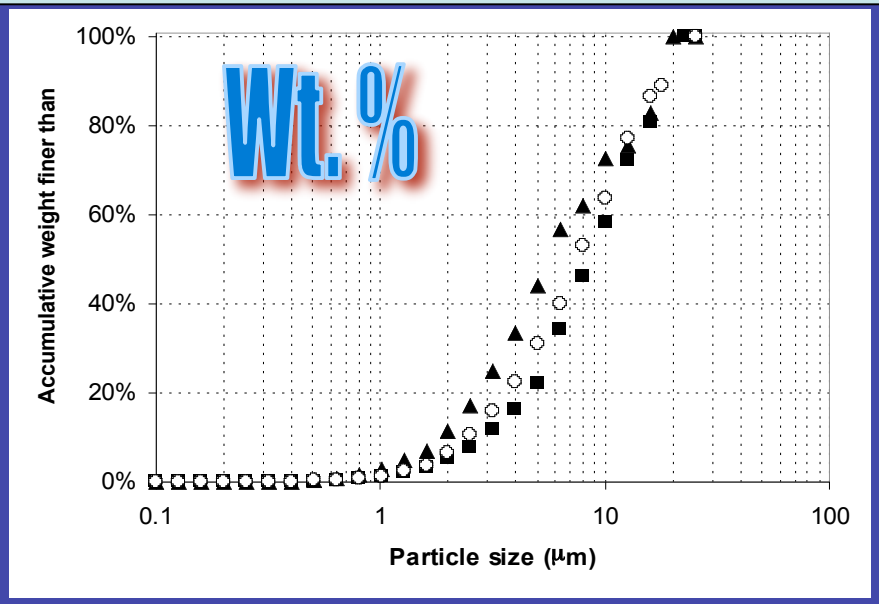
Approximately 50 wt% of Lunar Soil is < 50 μm

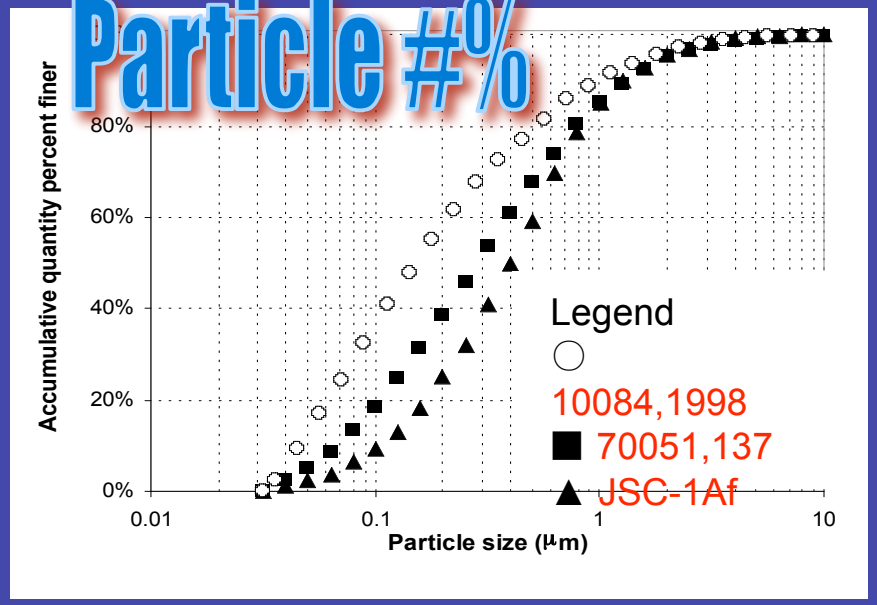
DUST = <20 μm = ~20 wt%

Lunar Dust is ~20 wt.% of the average mature Lunar Soil; then 2-5 wt% of that 20 wt% is <1 μm.

That is,

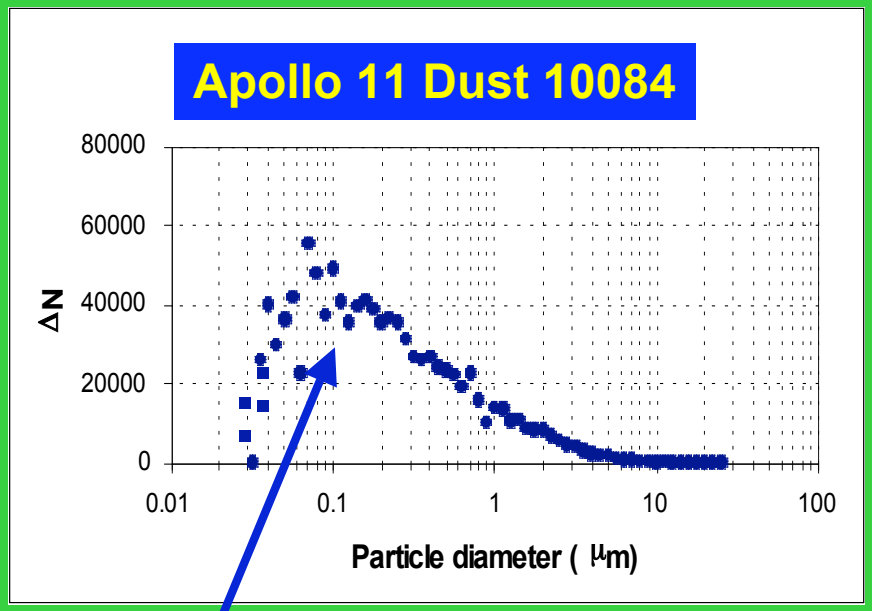
the <1 μm portion of the Soil is ~0.5-1 wt%



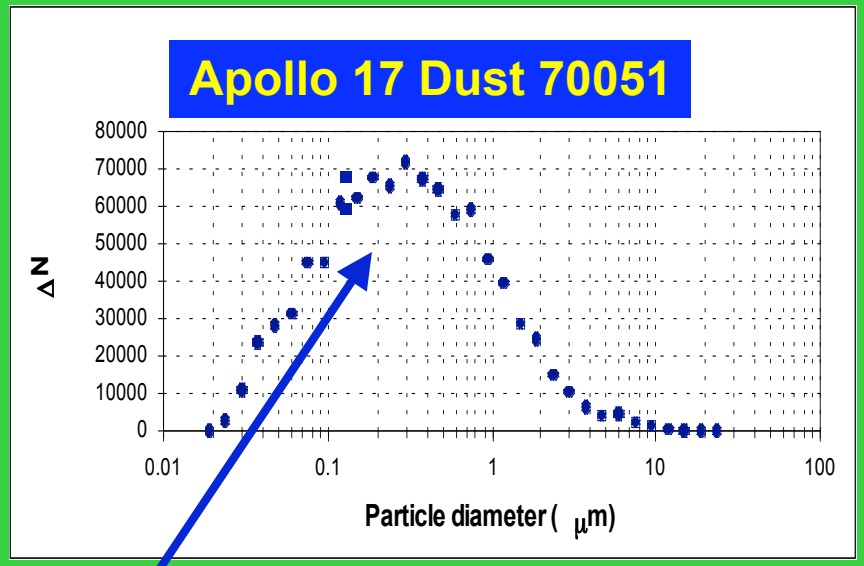


University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

PSD OF LUNAR MARE DUST



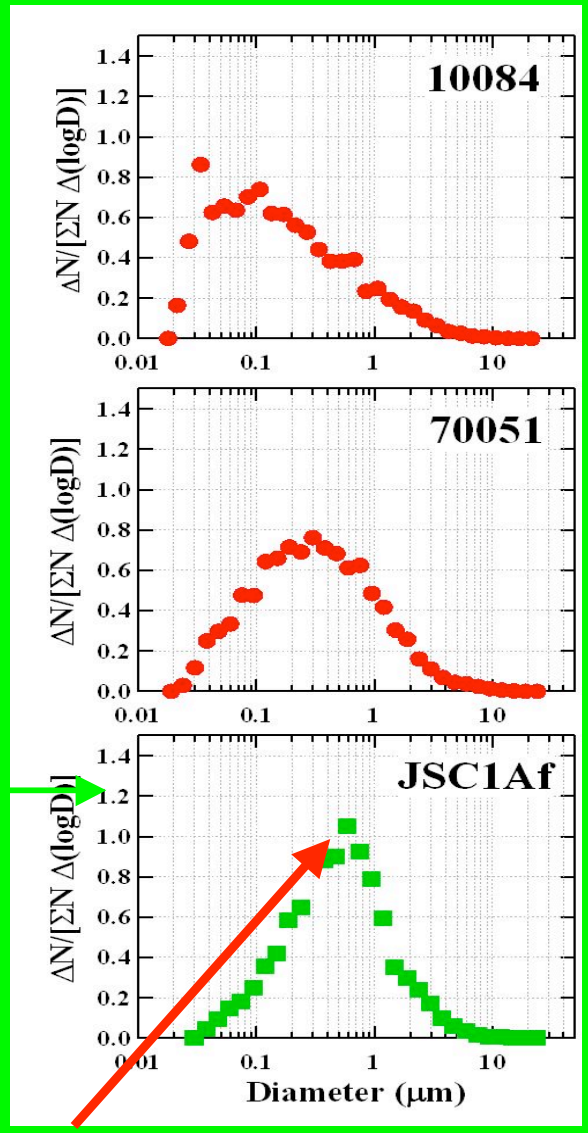
PSD by SEM



Max Particles ~ 100 nm

Max Particles ~ 200 nm

PSD of Lunar Mare Dust and JSC-1Avf



Lunar Dust Simulant, JSC-1Avf,

is NOT Suitable for Dust Studies,

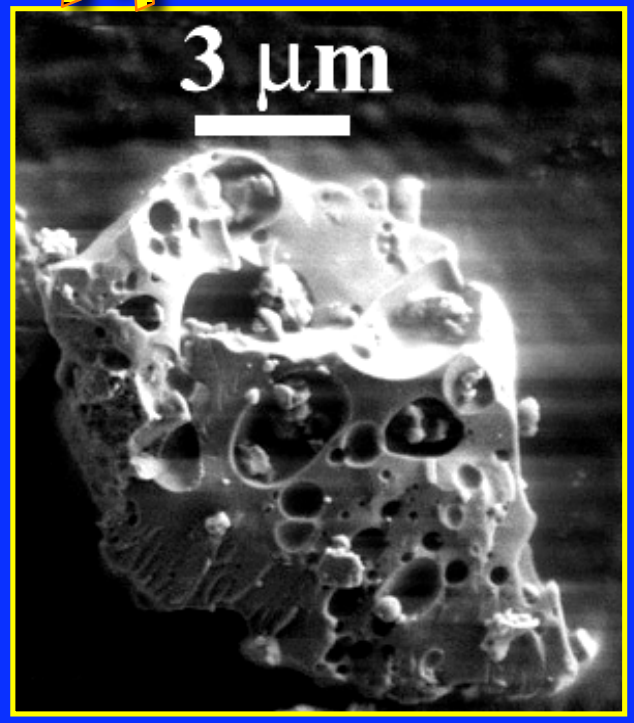
with regards to PSD

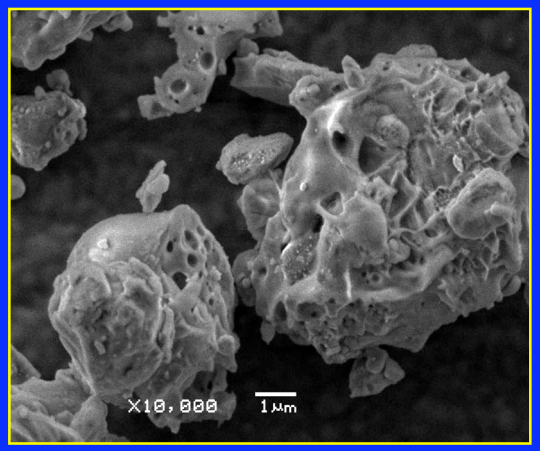
Max in Particles = ~700 nm

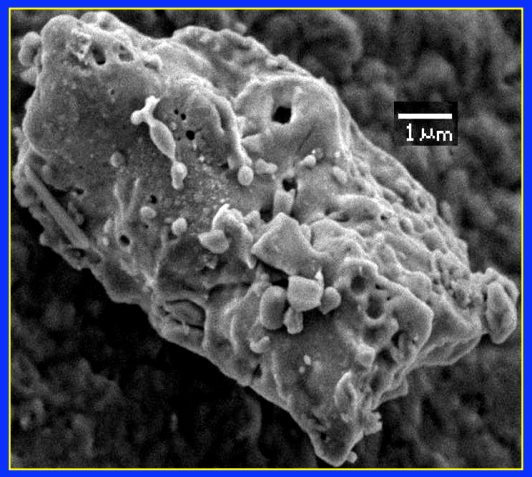
Park et al. (2006)

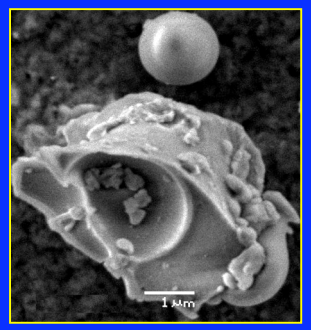
University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

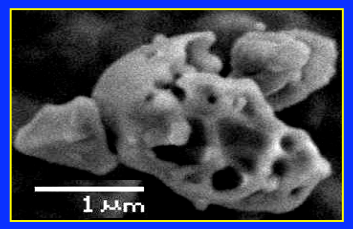
Apollo 17, 70051 Vesicular Dust Grains

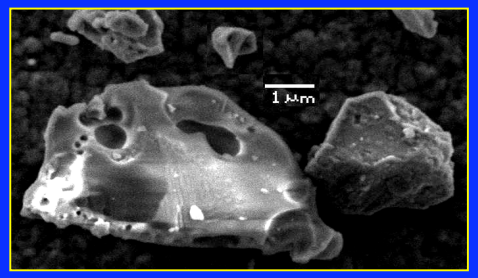










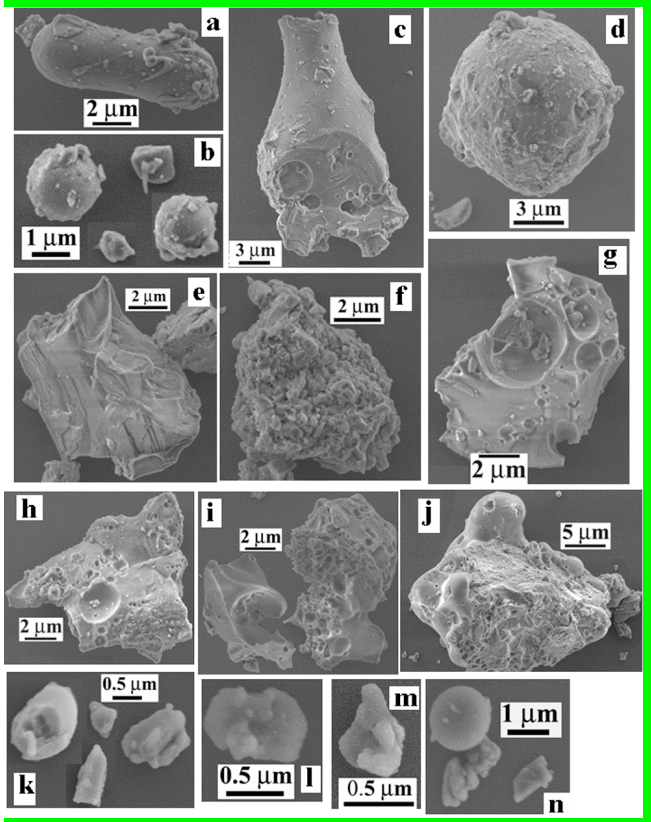


Increased reactive surface area

Liu et al. (2006)

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

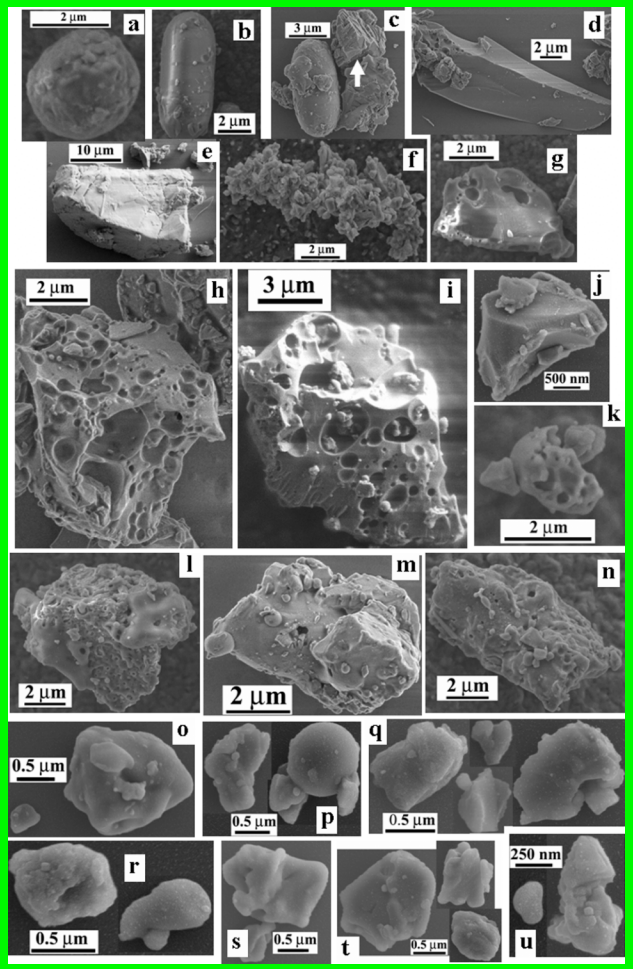
SEM Images

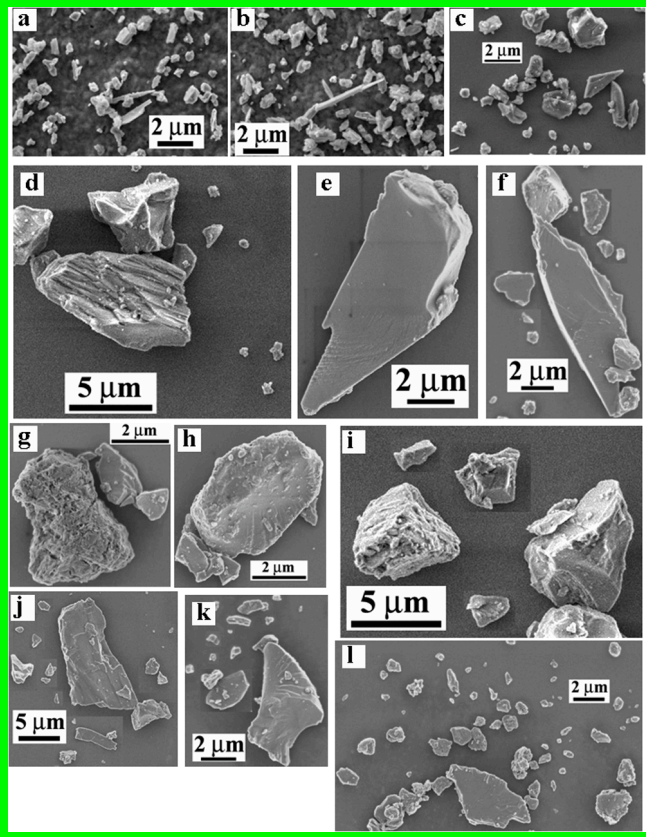


10084

Liu et al. (2006)

70051

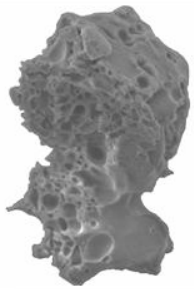
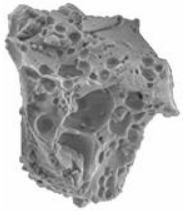
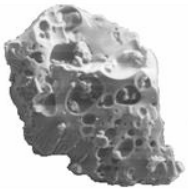
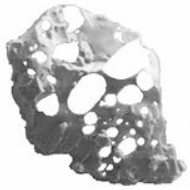




JSC-1Avf

Lunar Dust Simulant, JSC-1Avf, may not be Suitable for Dust Studies, with regards to PSD

Surface Area

Sample	Particle image	Vesicles on particle	Porosity, Area Ratio, Total number of vesicles
10084, 1998			$A_v/A_t = 0.13$ $P_t/P_{sp} = 2.15$ $\Sigma N_v = 110$
10084, 1998			$A_v/A_t = 0.30$ $P_t/P_{sp} = 1.88$ $\Sigma N_v = 24$
10084, 1998			$A_v/A_t = 0.18$ $P_t/P_{sp} = 3.61$ $\Sigma N_v = 154$
70051, 137			$A_v/A_t = 0.25$ $P_v/P_{sp} = 4.6$ $\Sigma N_v = 145$
70051, 137			$A_v/A_t = 0.26$ $P_v/P_{sp} = 2.23$ $\Sigma N_v = 39$

Park et al. (2006)

- SEM image of the particle is assumed to be a slice of 3D particle

3D		2D
Surface area	⇒	Perimeter
Volume	⇒	Area

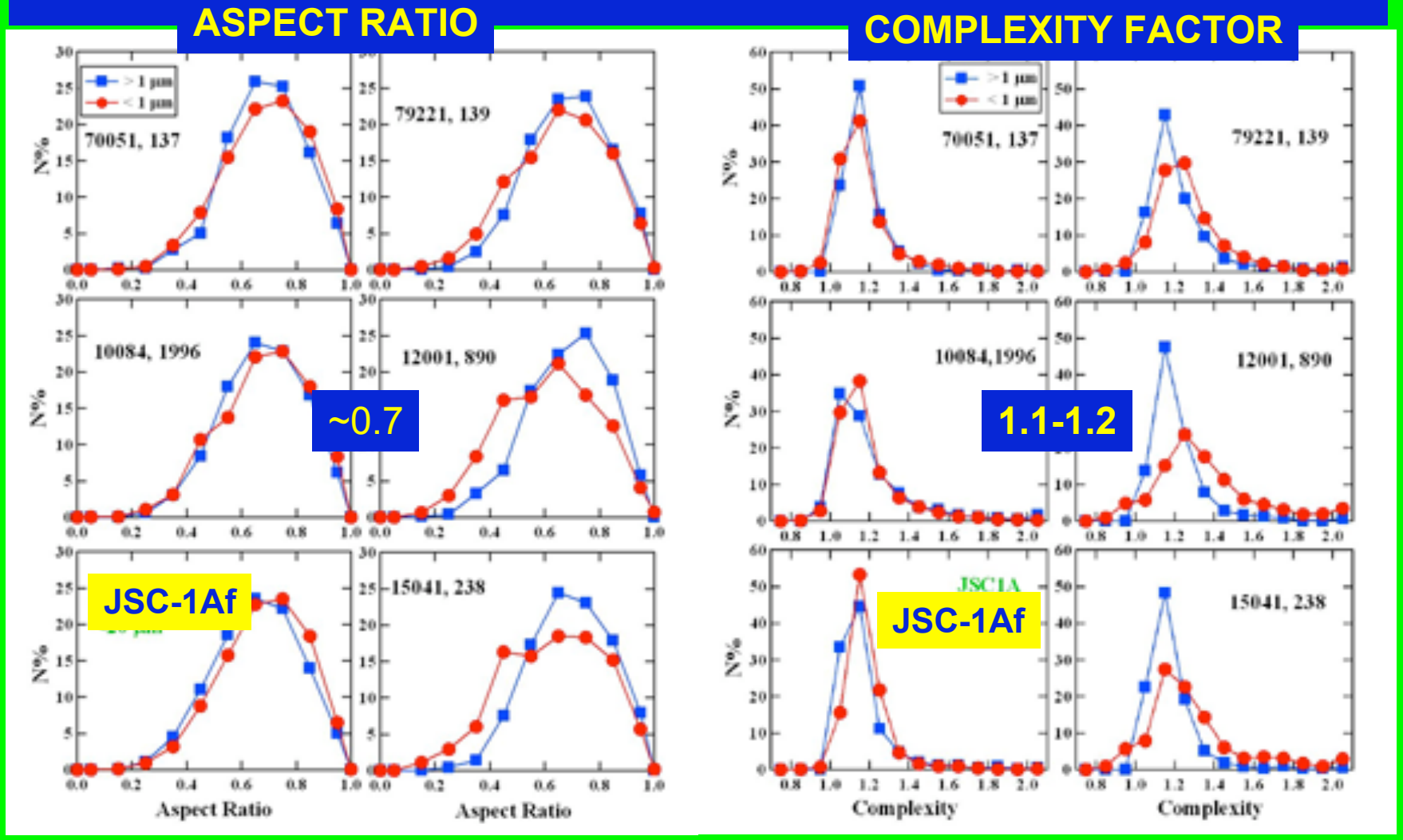
- Thus, P_v / P_{sp} is roughly the factor indicating the surface area increase

Av = total area of vesicles;
At = total area of particles;
Pv = total perimeter (vesicle-bearing particle);
Psp = the perimeter (vesicle-free particle);
ΣNv = the total number of vesicles.

Reaction Surface Areas are several times larger than external area alone

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Compare to Simulant JSC-1Avf



Dust Simulant JSC-1Avf approximates Lunar Dust

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Bulk Chemistry and *I*s/FeO Values of the <10 μm Fractions of Lunar Mare Soils

Soil # Maturity	10084 78	12030 14	12001 56	15071 52	15041 94	71061 14	71501 35	70181 47	79221 81
SiO_2	42.1	46.2	46.0	46.9	46.6	40.2	40.4	41.5	42.3
TiO_2	7.25	3.01	2.78	1.57	1.79	7.89	8.27	6.54	5.83
Al_2O_3	15.9	13.9	14.9	17.1	16.4	13.8	14.5	15.4	15.9
Cr_2O_3	0.27	0.43	0.42	0.40	0.37	0.44	0.40	0.39	0.35
MgO	7.20	8.37	8.79	9.85	9.37	9.18	8.76	9.12	9.59
CaO	12.3	10.4	11.2	11.8	11.6	10.7	11.2	11.5	11.7
MnO	0.19	0.19	0.19	0.15	0.17	0.20	0.19	0.18	0.17
FeO	12.0	14.3	12.5	9.59	11.0	14.8	13.5	12.7	11.3
Na_2O	0.46	0.53	0.51	0.48	0.49	0.46	0.42	0.46	0.49
K_2O	0.15	0.35	0.30	0.22	0.23	0.11	0.11	0.13	0.15
P_2O_5	0.20	0.32	0.24	0.09	0.20	0.05	0.06	0.10	0.07
SO_2	0.14	0.15	0.29	0.14	0.11	0.25	0.25	0.20	0.17
Total	98.16	98.14	98.12	98.30	98.35	98.19	98.11	98.16	98.10
I_s/FeO	145	32	115	159	161	28	88	104	169

LUNAR SOIL CHARACTERIZATION CONSORTIUM; Taylor et al (2001)

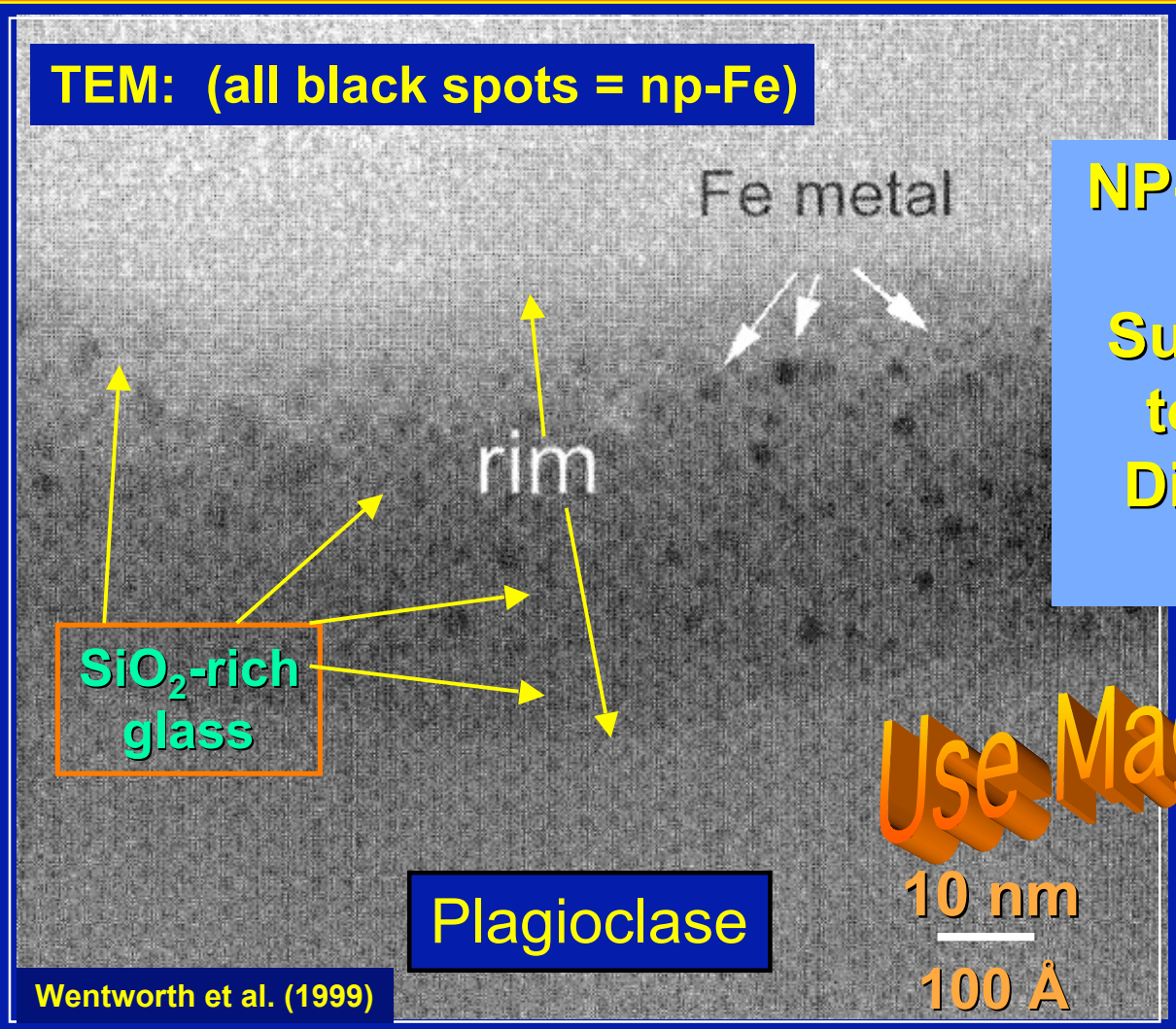
IMPACT GLASS CHEMISTRY

Taylor et al. (2001)

	10084 -78			12030 -14		
	20-45 μm	10-20 μm	<10 μm	20-45 μm	10-20 μm	<10 μm
SiO_2	44.5 (44)	45.2 (42)	44.5	47.8 (46)	47.9 (53)	47.7
TiO_2	2.96 (226)	2.94 (182)	3.30	2.74 (240)	2.53 190)	2.43
Al_2O_3	17.4 (75)	18.0 (80)	16.4	13.3 (59)	12.9 (62)	13.3
Cr_2O_3	0.31 (19)	0.24 (18)	0.24	0.32 (31)	0.36 (28)	0.34
MgO	8.69 (325)	8.45 (335)	8.68	8.73 (375)	8.81 (317)	8.97
CaO	13.2 (25)	13.9 (26)	13.2	11.6 (29)	11.7 (22)	11.6
FeO	10.6 (53)	10.2 (53)	11.8	13.7 (51)	13.5 (47)	13.6
Na_2O	0.36 (13)	0.36 (25)	0.33	0.46 (27)	0.48 (29)	0.44
K_2O	0.09 (7)	0.11 (7)	0.12	0.31 (24)	0.29 (22)	0.25
Total	98.11	99.35	98.49	98.82	98.47	98.56

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Vapor-Deposited Nanophase Fe° on Plagioclase



Wentworth et al. (1999)

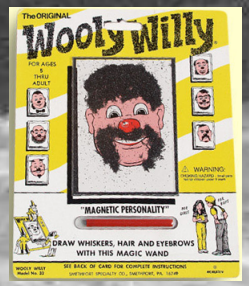
NP-Fe^0 Imparts Magnetic Susceptability to Normally Diamagnetic Feldspar

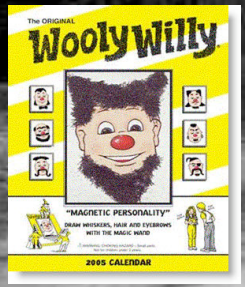
Use Magnets ?

Lunar Dust Can be Attracted to a Simple Magnet

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Lunar Soil



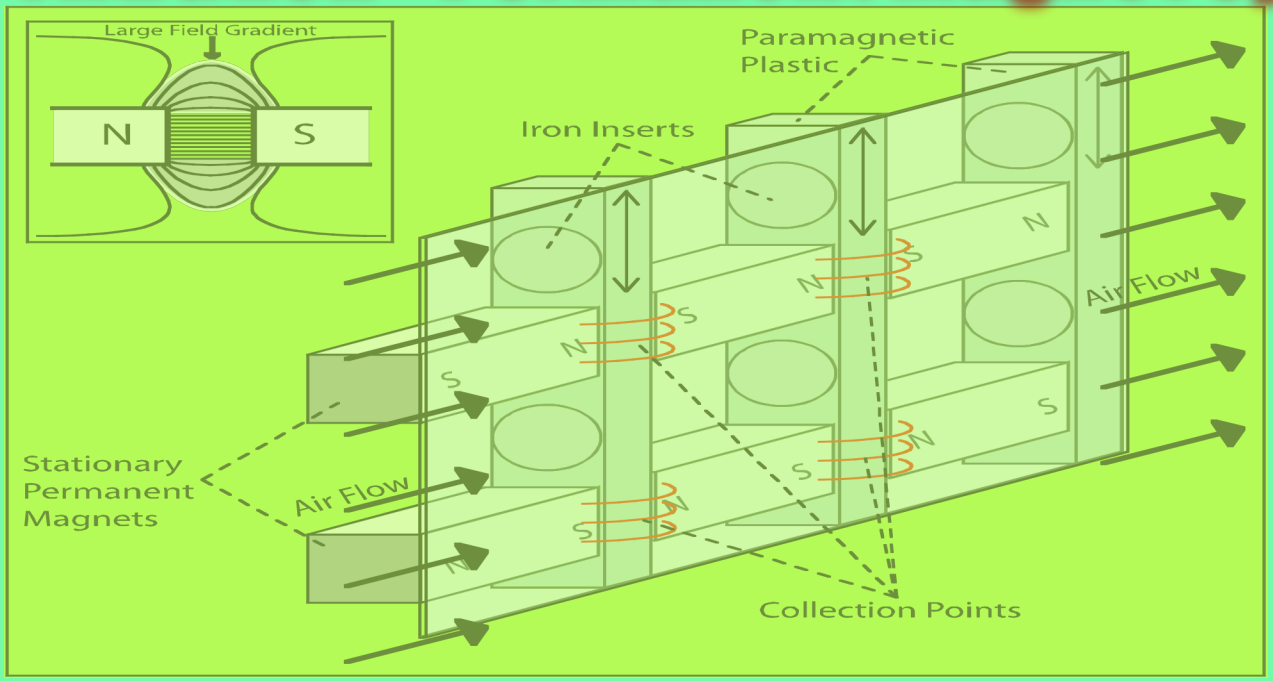


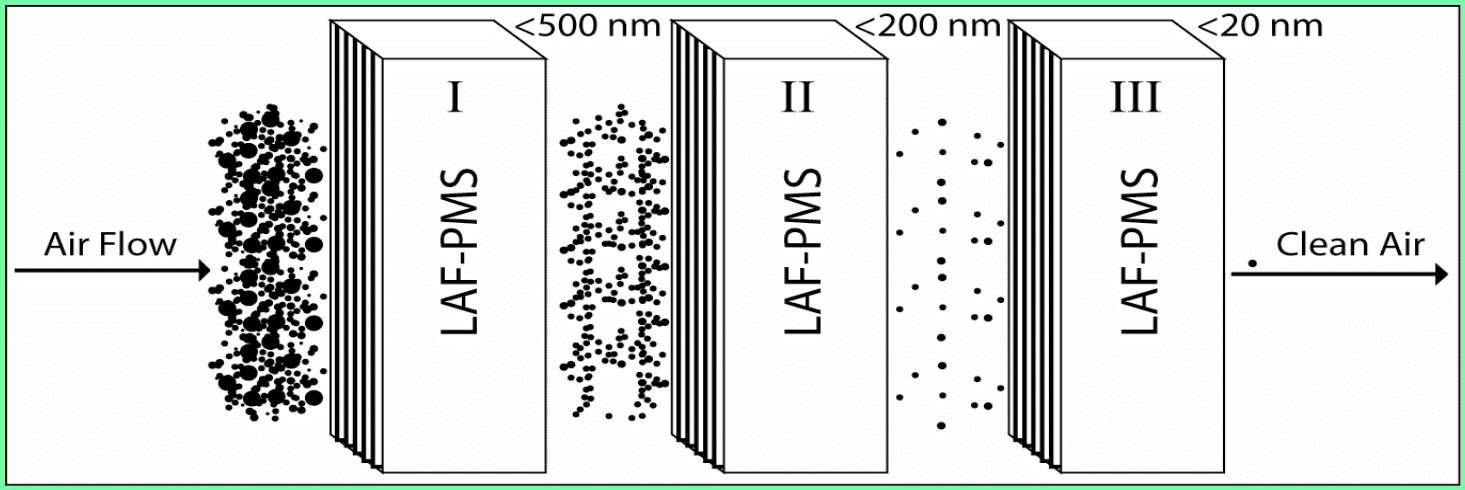
Apollo 11 10084: <45 µm

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Lunar Air Filtration - Permanent Magnet System

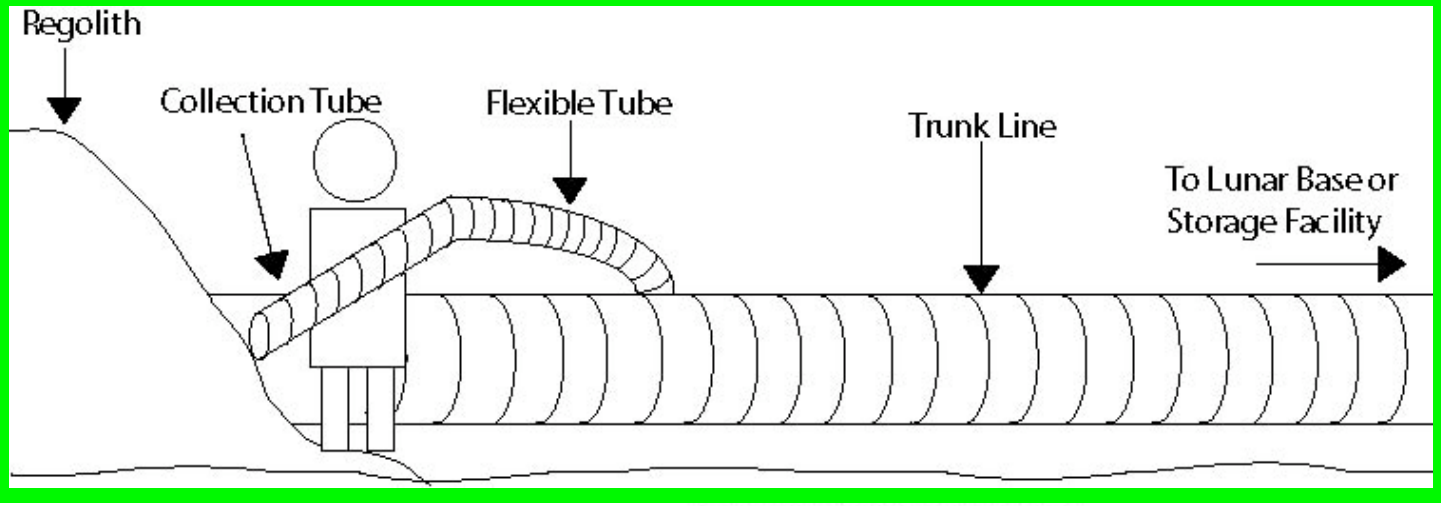
LAF-PMS

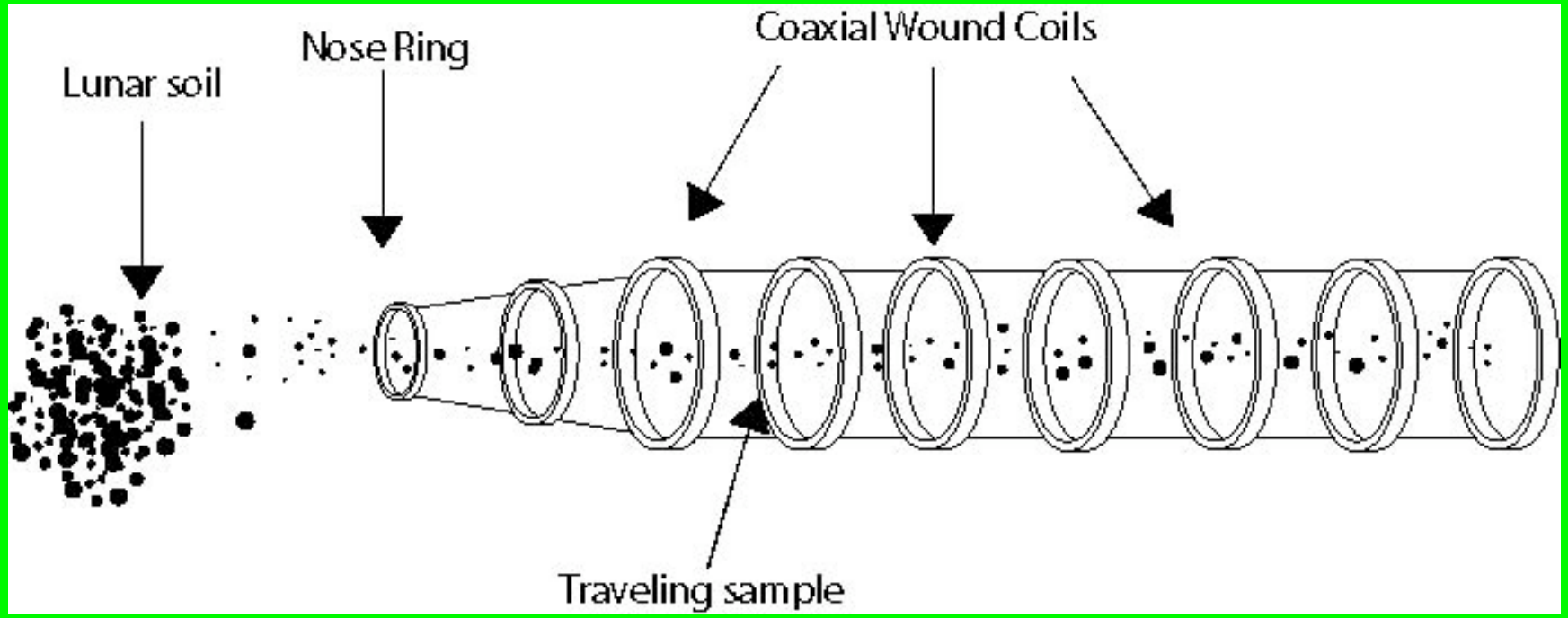




University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Lunar Soil MAgnetic Collector LSMAC

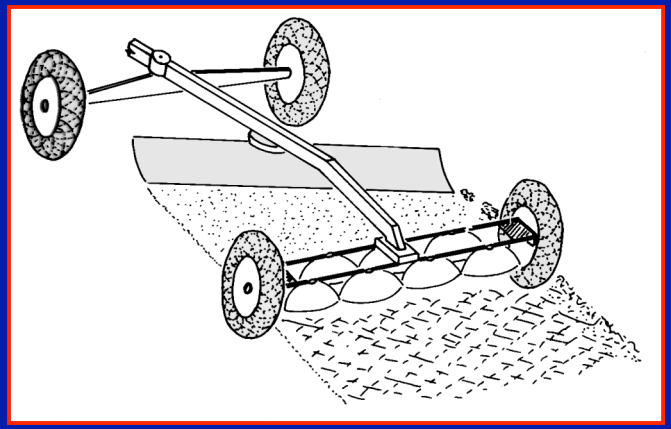




University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

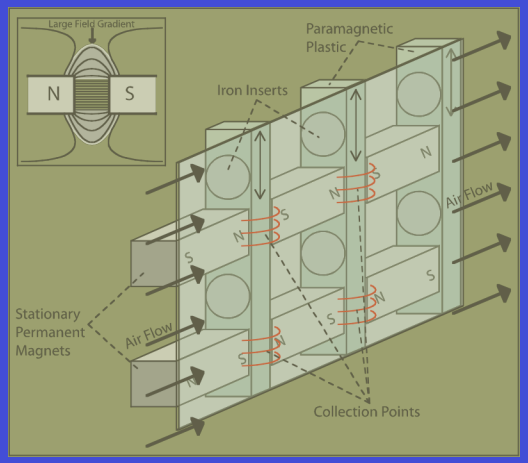
Microwave Heating of Lunar Soil

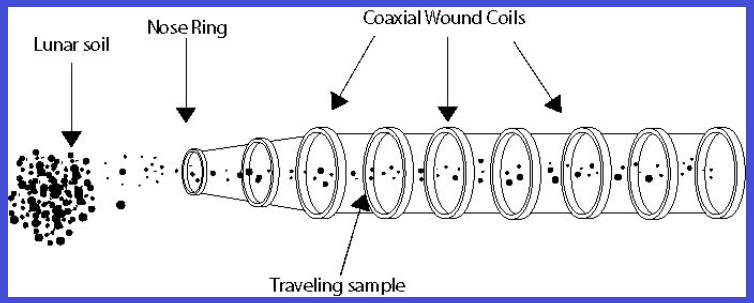
NanoPhase Fe^0 in Silicate Glass

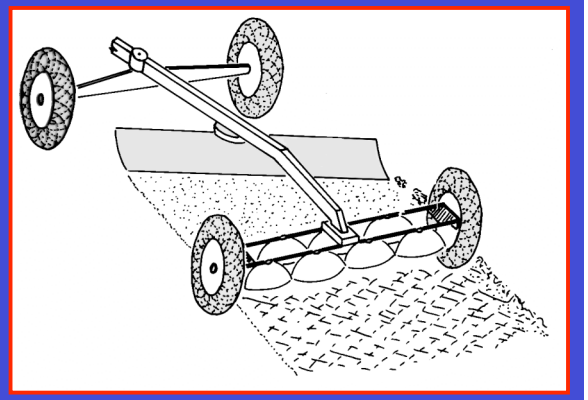


Lunar soil in your kitchen microwave oven will melt [~1200 ^{0}C], BEFORE your tea-water boils [100 ^{0}C]!!

(Taylor and Meek, 2005, Jour. Aerspace Engr.)







TAKE HOMES

- Lunar Dust Effects are a Major Problem;
- Dust (<20 μm) = ~20 wt% of Mature Lunar Soil;
- About 1 wt% of Mature Soil is < 1 μm;
- PSD of Mature Lunar Soil Peaks at ~100-200 nm;
- Impact Glass (with np-Fe) of < 1μm Dust = ~80 %;
- Dust Particle Morphologies are Unusual;
- Unique Properties of Soil are from Nanophase Fe:

  Magnetic Attraction; Microwave Coupling.